

Search for the Higgs boson decay to a low-mass dilepton system and a photon

Danning Liu

September 20th, 2026



מכון
והצמח
למדע

WEIZMANN
INSTITUTE
OF SCIENCE

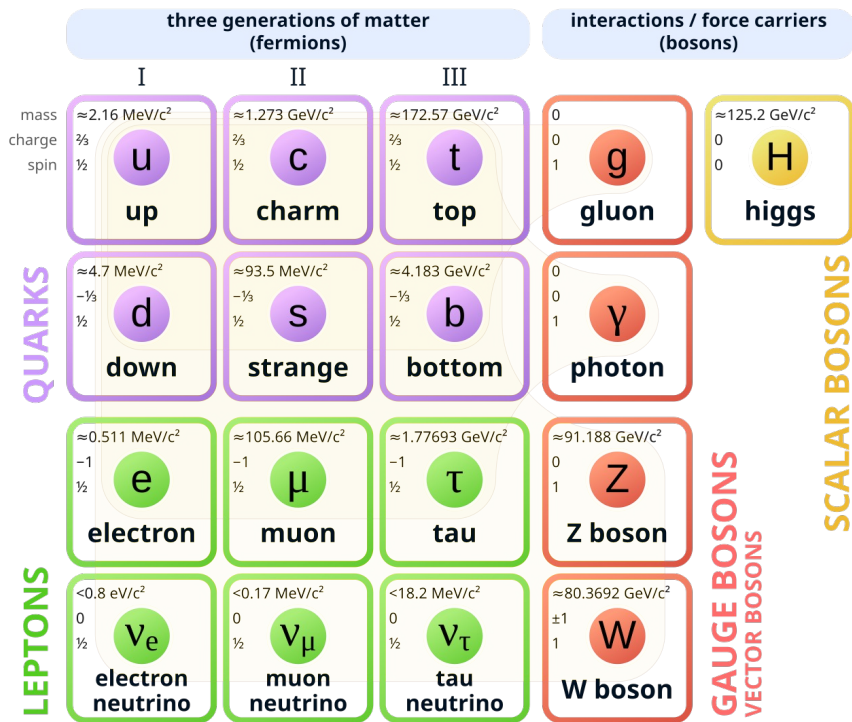


TECHNION

Israel Institute of Technology

Standard Model

Standard Model of Elementary Particles



► The Standard Model

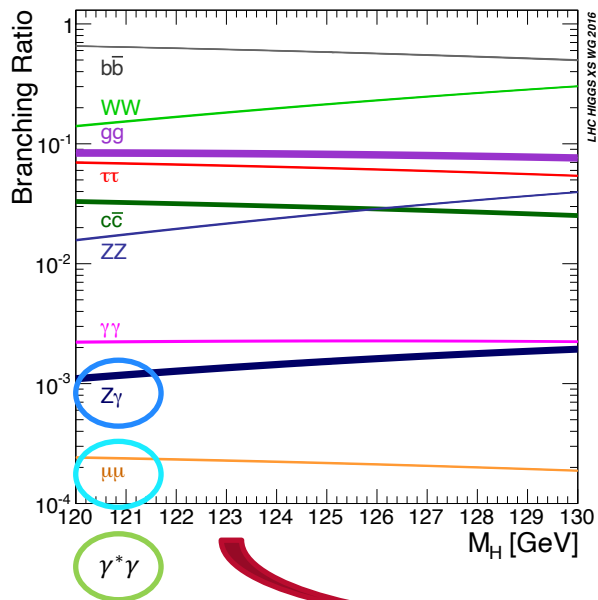
- A remarkably successful framework
- Describes elementary particles and their interactions through strong and electroweak forces
- Electroweak symmetry breaking (EWSB) generates W/Z masses through the Higgs mechanism
- The discovery of the Higgs boson completed SM as the last piece
- Being confirmed through collider measurements across a wide range of energies and processes

► Successful, but not the final story

Why search for rare Higgs decays

► Rare Standard Model Higgs decays

- interesting Higgs rare decays predicted by the SM but not observed yet

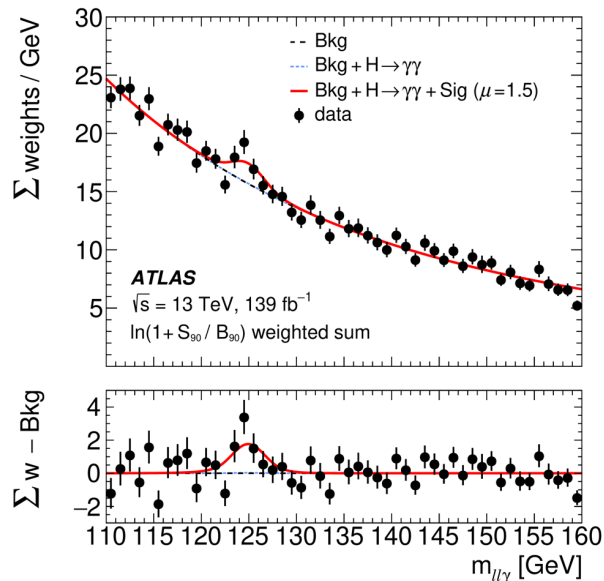
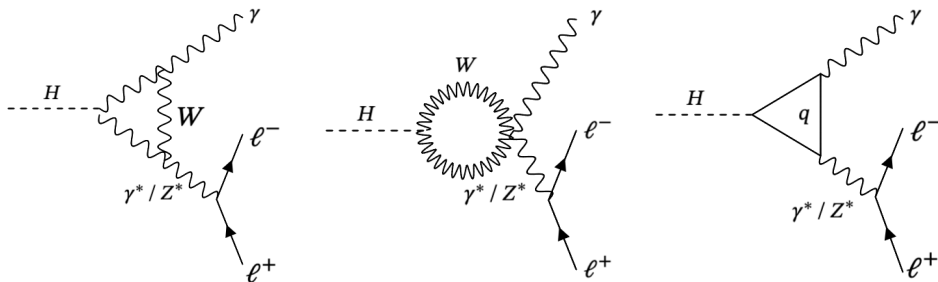


SM predictions @ $m_H = 125$ GeV

- $B(H \rightarrow \mu\mu) = 2.17 \times 10^{-4}$
- $B(H \rightarrow Z\gamma) = 1.54 \times 10^{-3}$, $B(H \rightarrow Z(\rightarrow ee/\mu\mu)\gamma) = 9.38 \times 10^{-5}$
- $B(H \rightarrow \gamma^*\gamma \rightarrow \ell\ell\gamma) = 3.4 \times 10^{-5} (\ell = e)$
 $= 7.2 \times 10^{-5} (\ell = \mu)$
- $B(H \rightarrow ee) = 5 \times 10^{-9}$

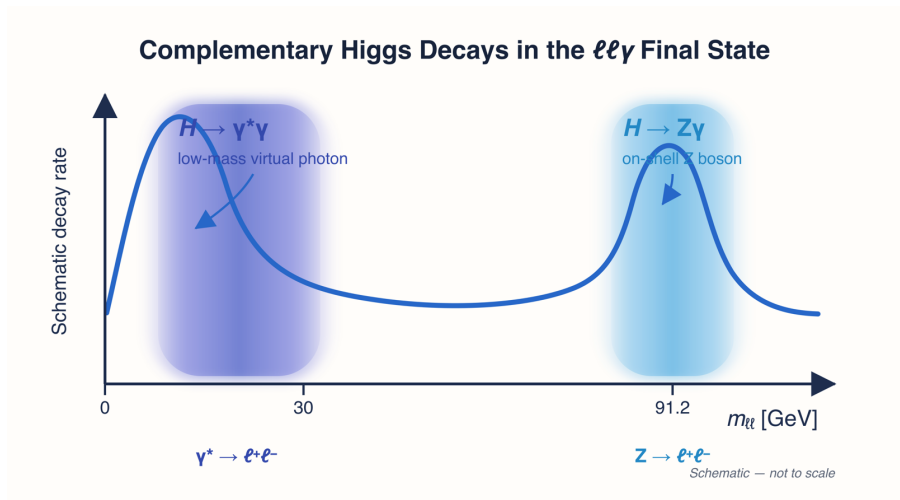
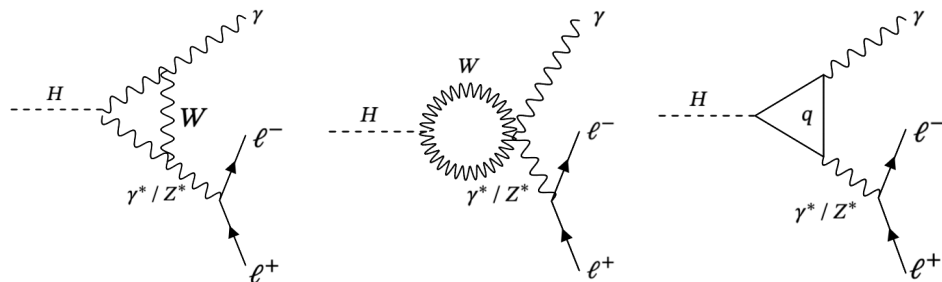
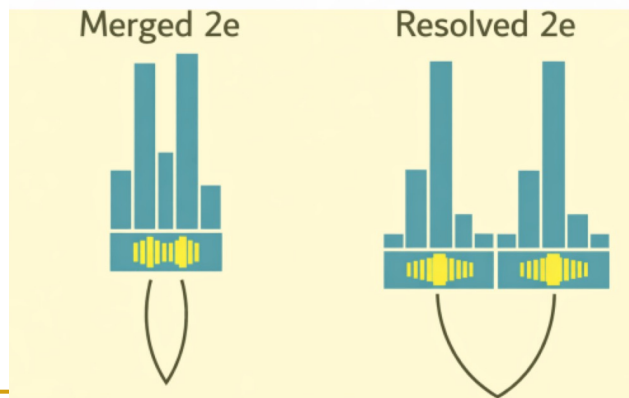
Physics Motivation

- ▶ Searching for rare decay process of Higgs boson ($H \rightarrow \gamma^* \gamma \rightarrow \ell \ell \gamma$, where ℓ decays into a pair of electrons or muons) with $m_{\ell\ell} < 30$ GeV
- Run-2 result:
 - First evidence of $H \rightarrow \gamma^* \gamma \rightarrow \ell \ell \gamma$ with an observed (expected) significance of 3.2 (2.1) σ
 - [Phys. Lett. B 819 \(2021\) 136412](#)
- Run-3 possibility:
 - More statistics and larger cross-section
 - Test of the loop-induced Higgs-photon interaction using ratio of $H \rightarrow \gamma^* \gamma$ and $H \rightarrow \gamma \gamma$ decay rates



Strategy

- ▶ Using 2022 + 2023 + 2024 datasets, ~ 164 fb
- ▶ Complementary study orthogonal to $H \rightarrow Z\gamma$
- ▶ Three channels are considered:
 - dimuon, merged electrons, and resolved electrons
 - Developed a dedicated BDT-based ID for merged electrons



Event selection

[arXiv: 2608.03369](https://arxiv.org/abs/2608.03369)

[HIGP-2024-16](#)

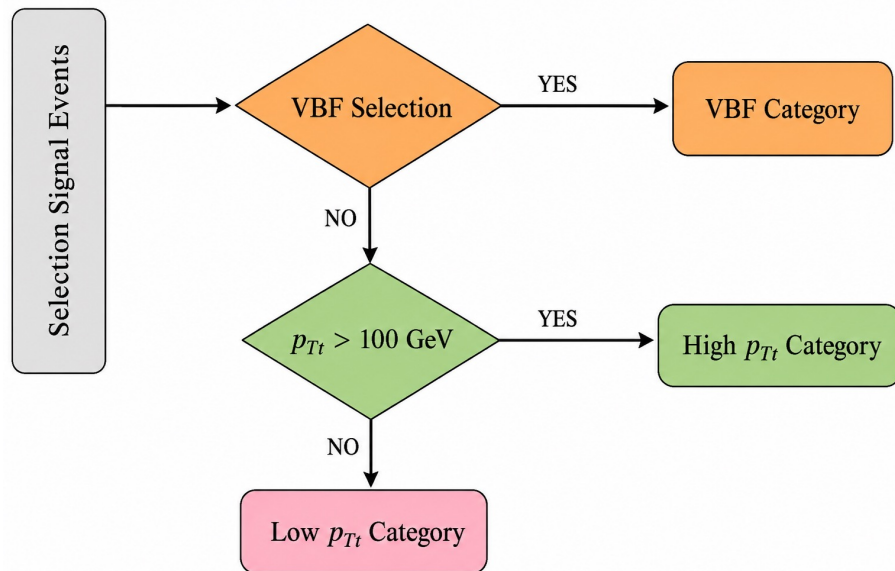


- ▶ Looking for events with at least two opposite sign same flavor leptons and one photon
 - $m_{\ell\ell} < 30$ GeV
 - $m_{\ell\ell\gamma} = [110, 160]$ GeV to target Higgs boson
- ▶ Trigger OR:
 - A combination of single-lepton, dilepton, photon, lepton+photon, and dedicated merged electron triggers is applied to maximize the signal acceptance

Suppress Drell-Yan process from Z bosons	→	$m_{\ell\ell} < 30$ GeV
Remove J/Ψ pair	→	$2.9 < m_{\mu\mu} < 3.3$ GeV, $2.5 < m_{ee} < 3.5$ GeV
Remove Υ candidate	→	$9.1 < m_{\mu\mu} < 10.6$ GeV, $8.0 < m_{ee} < 11.0$ GeV
Relative kinematic selection	→	$p_T^{\ell\ell}/m_{\ell\ell\gamma} > 0.3$, $p_T^{\gamma}/m_{\ell\ell\gamma} > 0.3$
Mass window	→	$m_{\ell\ell\gamma} \in [110, 160]$ GeV

Categorization

- ▶ Events in each channel are further categorized into VBF, high p_{Tt} , and low p_{Tt} , based on event topology
- ▶ p_{Tt} is defined as the transverse momentum projection onto the $\ell\ell\gamma$ thrust axis
- ▶ VBF category is assigned for priority
- ▶ High p_{Tt} events have harder kinematics and provide better S/B separation



Category	Selections
VBF	Jet multiplicity ≥ 2 , with $p_T > 25$ GeV $p_T > 30$ GeV if $ \eta > 2.5$ $m_{jj} > 500$ GeV $ \Delta\eta_{jj} > 2.7$ $ \eta_{\ell\ell\gamma} - 0.5(\eta_{j1} + \eta_{j2}) < 2.0$ $\Delta R(j_i, \ell) > 1.5, \Delta R(j_i, \gamma) > 1.5, i=1,2$ $ \Delta\phi(\ell\ell\gamma, jj) > 2.8$
High p_{Tt}	Failing the VBF selection and $p_{Tt} > 100$ GeV
Low p_{Tt}	Failing the VBF selection and $p_{Tt} \leq 100$ GeV

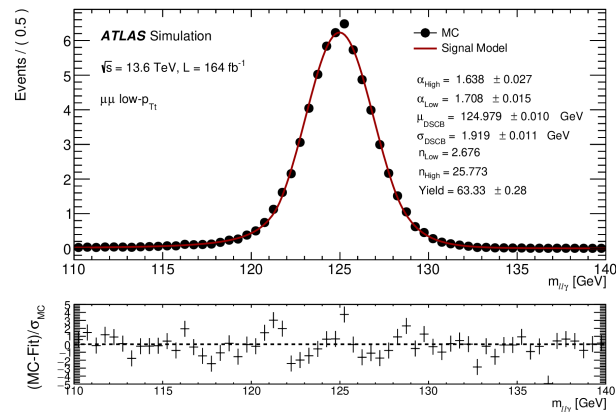
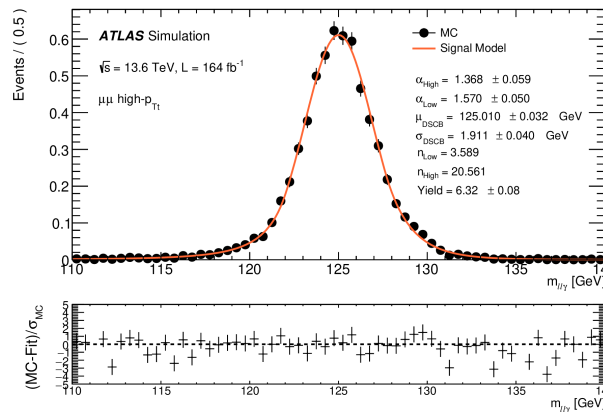
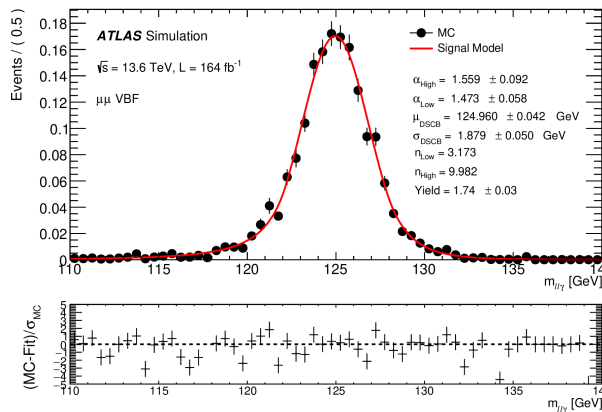
Signal modeling

arXiv: 2608.03369



HIGP-2024-16

- ▶ $H \rightarrow \gamma^* \gamma \rightarrow \ell \ell \gamma$ signal is modelled by a double-side Crystal Ball (DSCB) function in each category $\times$ channels (9 in total)
- Combining all production modes together with Standard Model cross-section

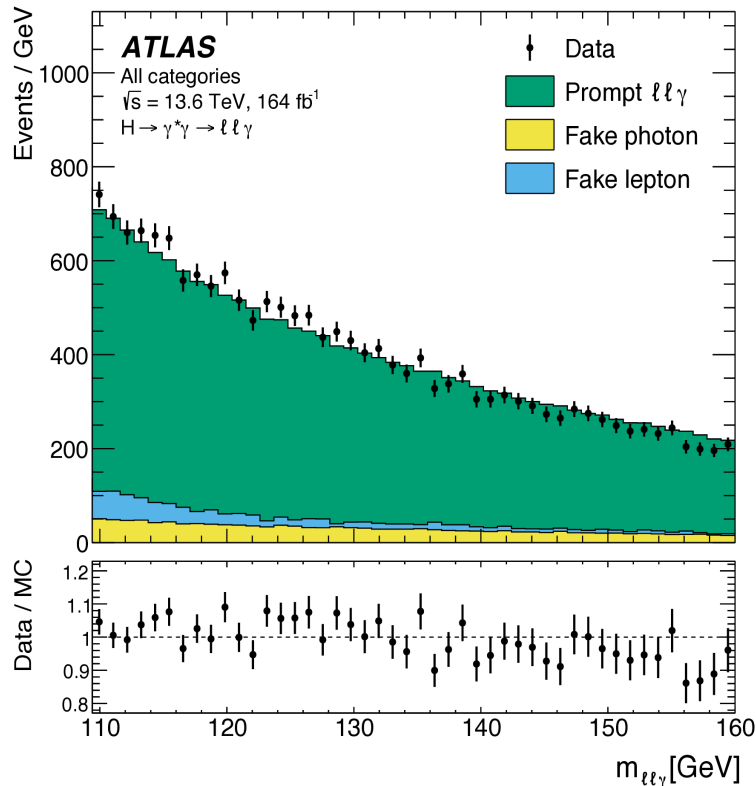


Background containmination

- Resonant background: $H \rightarrow \gamma\gamma$ with converted photon, only contribute to electron categories
- Non-resonant background: low-mass $\ell\ell\gamma$, estimated from MC simulation – **DOMINANT**
- Fakes: fake photon/lepton, estimated within the dedicated control regions using data-driven method
- All background contributions are summed up as background template for spurious signal study

arXiv: 2608.03369

HIGP-2024-16



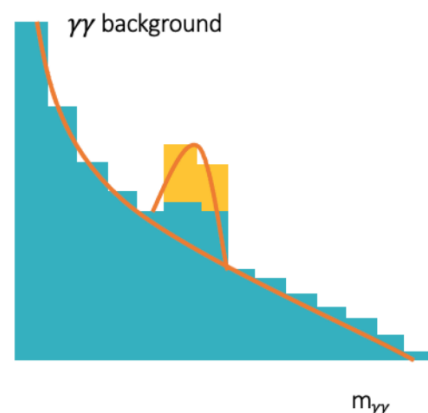
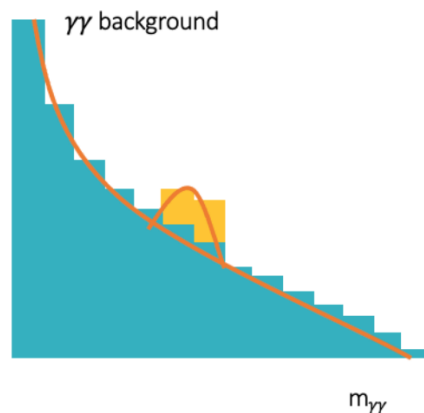
Background modeling

[arXiv: 2608.03369](https://arxiv.org/abs/2608.03369)



[HIGP-2024-16](#)

- ▶ A spurious signal test is performed to select analytical functions for describing background distributions
- ▶ What is spurious signal?
 - Spurious signal is “fake signal” yield obtained when the background model failed to describe the real background shape
- ▶ Procedure to perform spurious signal test
 - Construct background template
 - Criteria for selecting functions
 - The spurious signal must be smaller than 20% of the expected statistical uncertainty of fitted signal yield
 - The spurious signal must be smaller than 10% of the expected signal yield
 - Good fit quality



Background modeling

arXiv: 2608.03369

HIGP-2024-16



- ▶ A spurious signal test is performed to select analytical functions for describing background distributions
- ▶ Resonant background: $H \rightarrow \gamma\gamma$ with converted photon, only contribute to electron categories
- ▶ Non-resonant background: low-mass $\ell\ell\gamma$, estimated from MC simulation – **DOMINANT**
- ▶ Fakes: fake photon/lepton, estimated within the dedicated control regions using data-driven method
- ▶ All background contributions are summed up as background template for spurious signal study

Function	Categories	Definition
First-order exponential	$\mu\mu$ VBF	$\text{Exp}(m_{\ell\ell\gamma}; \theta^{\text{bkg}}) = \exp\left(\sum_{j=0}^1 \theta_j^{\text{bkg}} \cdot m_{\ell\ell\gamma}^j\right)$
	ee resolved VBF	
	ee merged VBF	
	$\mu\mu$ high p_{T1}	
	ee merged high p_{T1}	
Power-law	$\mu\mu$ low p_{T1}	$\text{Pow}(m_{\ell\ell\gamma}; \theta^{\text{bkg}}) = m_{\ell\ell\gamma}^{\theta^{\text{bkg}}}$
	ee resolved high p_{T1}	
FK1	ee resolved low p_{T1}	$f_{1;d}(x; b, \{a_1\}) = (1 - x^d)^b x^{\sum_{j=0}^1 a_j \log(x)^j}$, $x = \frac{m_{\ell\ell\gamma}}{\sqrt{s}}$
Bern2	ee merged low p_{T1}	$\text{Bern}^2(m_{\ell\ell\gamma}; \theta^{\text{bkg}}) = \sum_{j=0}^2 \theta_j^{\text{bkg}} b_{j;2}$, $b_{j;2} = C_n^j x^j (1 - x)^{2-j}$, where $x = (m_{\ell\ell\gamma} - 100)/60$

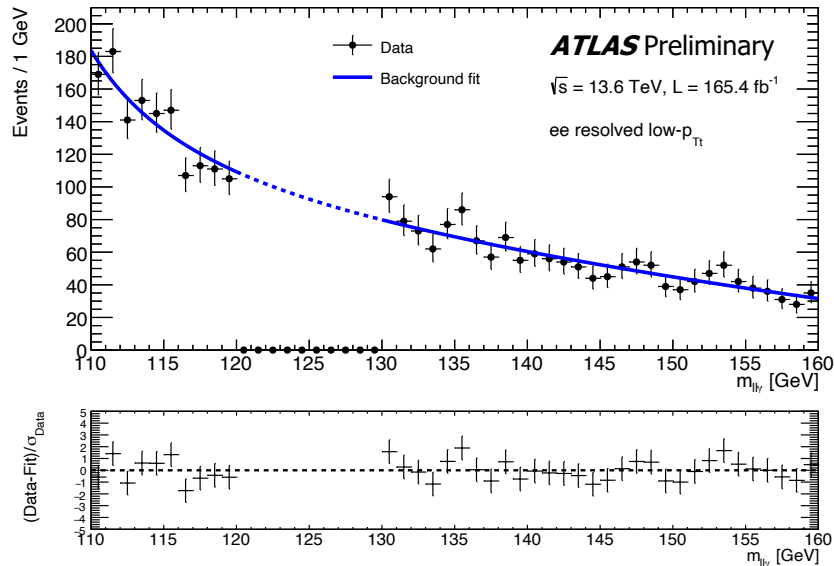
Background modeling

arXiv: 2608.03369



HIGP-2024-16

- ▶ The background templates are used to selection analytical function forms for describing distributin shapes
- ▶ Once functions determined, the parameters are obtained in each channel $\times$ each category by fitting to data in the sideband region ($110 < m_{\ell\ell\gamma} < 120$ GeV, and $130 < m_{\ell\ell\gamma} < 160$ GeV)
- ▶ In general, the fit qualities are good



Run-3 result

arXiv: 2608.03369



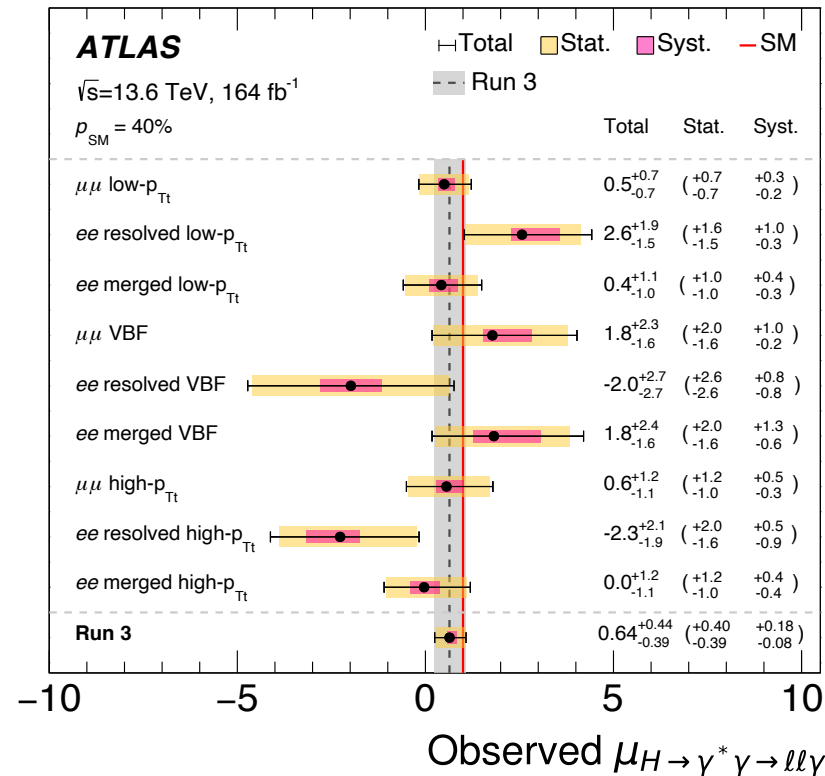
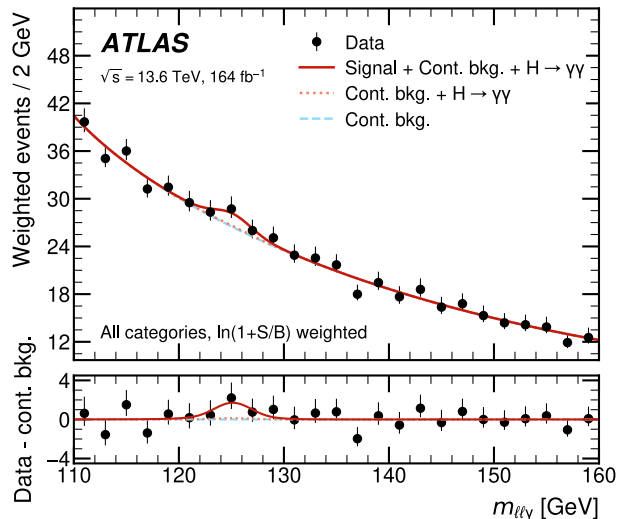
HIGP-2024-16

► The observed result:

- $\mu = 0.64^{+0.44}_{-0.39} = 0.64^{+0.40}_{-0.39}(\text{stat.})^{+0.18}_{-0.08}(\text{syst.})$
- $Z_{obs} = 1.7 \sigma$

► The expected result:

- $\mu = 1.00^{+0.47}_{-0.41} = 1.00^{+0.41}_{-0.40}(\text{stat.})^{+0.23}_{-0.11}(\text{syst.})$
- $Z_{exp} = 2.5 \sigma$



Run-2 and Run-3 combination

arXiv: 2608.03369

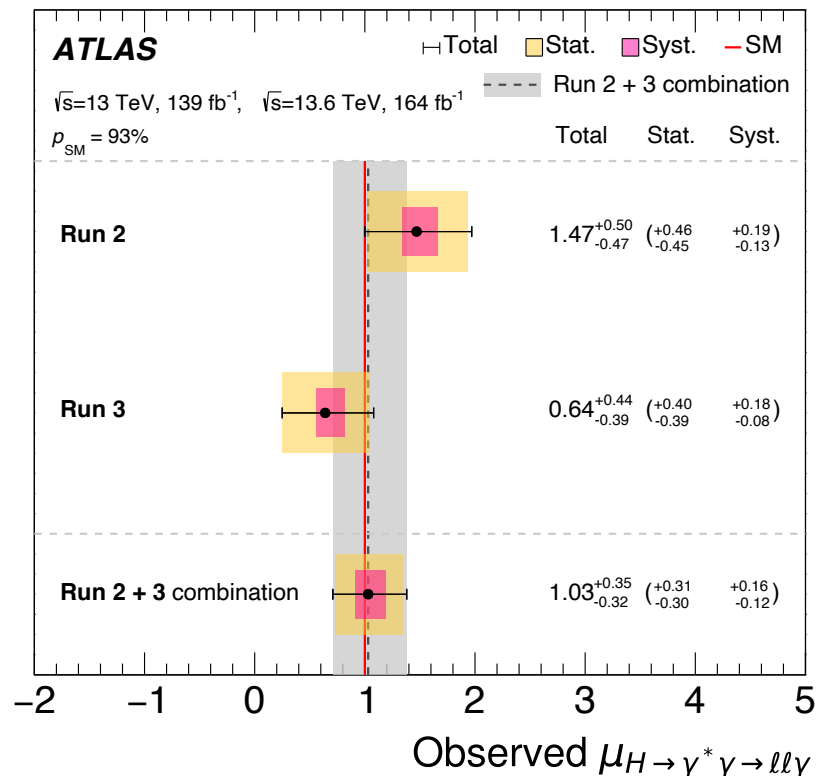
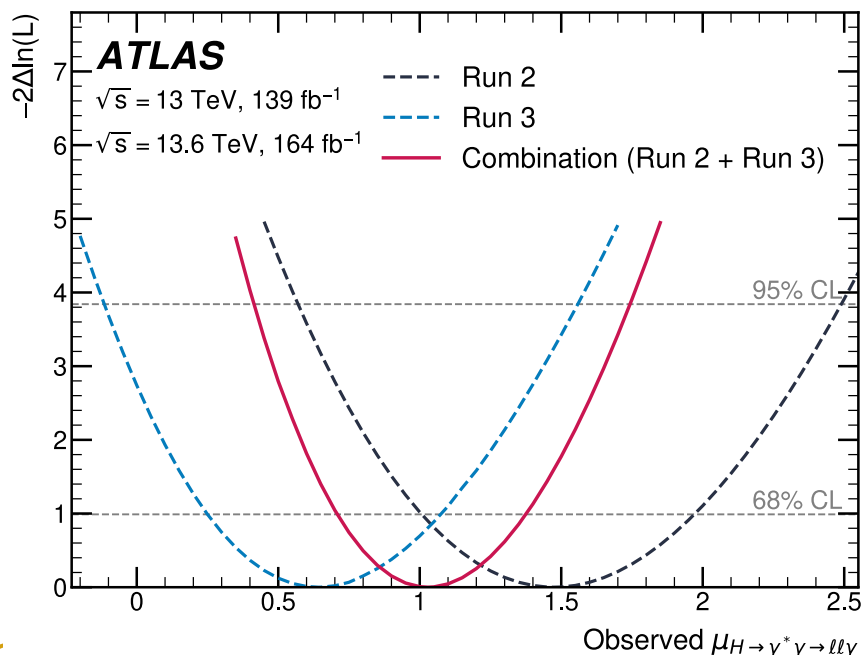
HIGP-2024-16



► The observed result:

— $\mu = 1.03^{+0.35}_{-0.32} = 1.03^{+0.31}_{-0.30}(\text{stat.})^{+0.16}_{-0.02}(\text{syst.})$

— $Z_{\text{obs}} = 3.4 \sigma$



Summary

- ▶ The search for the Higgs boson decay to a low-mass dilepton system and a photon was performed, using the datasets during 2022 – 2024 at $\sqrt{s} = 13.6$ TeV, with an integrated luminosity of 164 fb
- ▶ Run 3 only:
 - Observed signal strength: $\mu = 0.64^{+0.44}_{-0.39}$
 - Significance: 1.7 (2.5) σ for observed (expected)
- ▶ Run 2 and Run 3 combination
 - Observed signal strength: $\mu = 1.03^{+0.35}_{-0.32}$
 - Significance: 3.4 (3.3) σ for observed (expected)

[arXiv: 2608.03369](https://arxiv.org/abs/2608.03369)

[HIGP-2024-16](#)

